Renewable and Sustainable Energy Reviews 33 (2014) 392–399

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Diffusion of eco-innovations: A review

Emrah Karakaya [a,b,*], Antonio Hidalgo [a], Cali Nuur [b]

[a] Department of Industrial Engineering, Business Administration and Statistics, ETSII, Universidad Politécnica de Madrid, Spain
[b] Department of Industrial Economics and Management (INDEK), KTH, Royal Institute of Technology, Sweden

ARTICLE INFO

Article history:
Received 22 August 2013
Received in revised form
13 January 2014
Accepted 31 January 2014
Available online 5 March 2014

Keywords:
Eco-innovations
Diffusion
Innovation studies
Review

ABSTRACT

Literature in the field of eco-innovations often focuses on policy, regulations, technology, market and firm specific factors rather than diffusion. However, understanding of diffusion of eco-innovations recently has gained more importance given the fact that some eco-innovations are already at a mature stage. This paper aims to clarify the concept of diffusion of eco-innovation and provide a current overview of this emerging literature. Within this review framework, we identify the most cited relevant publications and corresponding research streams. We also describe the strengths and limitations of these research streams in the concept of diffusion of eco-innovations. The results summarize insights from different research streams in different disciplines and outline an entry point for researchers new to the emerging field of diffusion of eco-innovations.

Contents

1. Introduction

In an era characterized by discussions on impending climate change and the urgency to mitigate it, the policy discourse on the necessity of stimulating environmentally friendly innovations has grown. The hope is that the emergence of eco-innovations will reduce dependency on fossil based natural resources and decrease the release of harmful substances across the whole life-cycle [12]. In this context, for example, the European Union aims to achieve a resource-efficient Europe and an economic growth with eco-innovations [13,12]. However, there are two significant barriers to implement eco-innovations that need to be overcome before they are embraced by consumers. These are market uncertainty and uncertain return on investment [11].

* Corresponding author. Tel.: +46 87906718.
E-mail addresses: emrahka@kth.se (E. Karakaya), antonio.hidalgo@upm.es (A. Hidalgo), cali.nuur@indek.kth.se (C. Nuur).

http://dx.doi.org/10.1016/j.rser.2014.01.083
1364-0321

Empirical evidence shows that some environmental innovations require a lengthy period of time before they are adopted, which are directly related to their diffusion rate and diffusion path.

In general, diffusion of an innovation is defined as a process by which an innovation is communicated through certain channels over time among the members of a social system [46]. The diffusion of innovations theory [50,51] is one of those that help us to understand how eco-innovations are diffused. The theory focuses on the process and the conditions at which innovations and ideas become diffused and adopted by users/customers within wider social networks. Although based on a sociological perspective, Roger's approach [50,51] has today widely permeated to the fields of management, economics, communications and marketing [15], and is applied to different types of innovations. However, the relevance of the theory to explain the diffusion of eco-innovations is not known yet.

In the literature there are already some evidences concerning the knowledge base of eco-innovation focused on management of eco-innovations and eco-innovation terminology [53], and green supply chain management [52]. However, there is no comprehensive review on the knowledge base of diffusion of eco-innovations, which differs from other innovations given the political dimensions underlying their emergence. Understandably, eco-innovations, especially renewable energy technologies, need political support and have a global market potential based on global concerns and discourses that there is an imminent global warming. Eco-innovations cannot be treated like other innovations (e.g. in terms of the double externalities and the regulatory push/pull effect), and a specific theory and policy are needed [48].

Building on the previous studies on the knowledge base of innovation studies [16,15] and eco-innovations studies [52,53], the aim of this paper is to make a synthesis of the empirical state-of-the-art literature on diffusion of eco-innovations and identify the most relevant research streams. In order to achieve this, four main steps are followed: First, definitions associated to diffusion of innovations and eco-innovations are presented and clarified. Second, a set of keywords are identified in order to increase the search efficiency. Third, a database of publications from Google Scholar database is compiled based on the keywords. Last, the findings within 5 disciplines and research traditions are presented in order to contribute to understand the diffusion of eco-innovations.

The rest of the paper is organized as follows. Next section is dedicated to analyze the different concepts used to describe diffusion of innovations and eco-innovations. Section 3 describes the research approach and methodology used to compile and analyze the data resulting of our literature review. The findings of the analysis are summarized in Section 4, and Section 5 presents the discussions on the findings. Finally, Section 6 presents the conclusions and the recommendations for future research.

2. Diffusion of innovations and eco-innovations

2.1. Diffusion of innovations

Research on diffusion is an interdisciplinary field, and the philosophical undertones have its roots in the studies from sociology [58] and anthropology [63,64]. It has attracted scholars in a variety of disciplines, including economics [23,36] and marketing [5]. Rogers [51] defines diffusion as "the process by which an innovation is communicated through certain channels over time among the members of a social system". It is a special type of communication related with ideas that are perceived as new. This definition contains the four elements of innovation diffusion: the innovation, the communication channels, the time, and the social system. The first element, innovation, is described as an idea, practice, or object that is perceived as new by individual or other unit of adoption. The second element, communication channel, is the means by which messages get from one individual to another. This communication can be either through informing or persuading. Informing potential adopters about the existence of an innovation are usually performed by mass media communication channels such as television and Internet. However for persuading an individual to start using an innovation, interpersonal communication channels are supposed to be more efficient since these involve face-to-face exchange among the individuals. The third element, time, is involved in diffusion through the process which an individual (or other decision-making unit) passes from first knowledge of an innovation to forming an attitude toward the innovation, to a decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision. The fourth element of innovation diffusion, social system, is defined as a set of interrelated units that are engaged in joint problem-solving to accomplish a common goal. The social structure of the system affects the innovation diffusion in several ways through the social norms, opinion leaders and social consequences. According to this definition, "innovativeness and adopter categories" and "rate of adoption" are critical aspects since the diffusion of innovations is based on innovativeness degree of individuals and the characteristics of an innovation. Rogers [50] classified the categories of the adopters as innovators, early adopters, early majority, late majority and laggards, corresponding to different stages of consumer´s adoption during market development, and also explains the characteristics of an innovation as relative advantage, compatibility, complexity, trialability (the degree to which an innovation may be experienced on some limits) and observability, as perceived by the members of a social system.

Actually, there is a vast and highly fragmented literature on diffusion of innovations. It is possible to identify different approaches to diffusion of innovations, each focusing on specific aspects of diffusion through different perspectives. The main contributions come from economics, marketing, sociology and anthropology [59]. Economists have developed different econometric models to explain the diffusion of new products and specific technologies based on costs and past behavior of the consumers. Marketing studies have adopted a wide range of different research instruments oriented to explain the buyer behavior. Social studies have been focused to examine the sociological and psychological factors that influence the diffusion of innovations, and most of the anthropological studies have been based on case studies of the diffusion of new ideas, doctrines and information in villages or communities. But more recently, multidisciplinary research has been growing examining the diffusion of educational, medical and other policy innovations.

Research on diffusion tries to identify the factors that influence the rate and direction of the adoption of an innovation [21]. In practice, the pattern of the adoption of an innovation depends on the interaction of different factors that can be grouped as follows: supply-side factors (availability of information, relative advantage of the innovation, barriers to adoption and feedback between suppliers and consumers); demand-side factors (adopters with different perceptions, imitation of early adopters) [59]; and cross-country factors (culture, religion, opinion leaders). The choice between the different models of diffusion of an innovation and the factors which will most influence its adoption will depend on the characteristics of the innovation and the nature of potential adopters.

2.2. Eco-innovations

Eco-innovations refer to wide range of innovations such as renewable energy technologies, pollution prevention schemes, waste management equipments, green financial products and biological agriculture [34]. The term of "eco-innovation" (ecological

innovation) has been introduced into the literature long after the first examples of diffusion models appeared. Currently there are different definitions. One of the first definitions is from Fussler and James [19] (as cited in [53]). They define eco-innovation as “new products and processes that provide customer and business value but significantly decrease environmental impact”. Kemp and Pearson [33] define eco-innovation in a similar approach as “the production, adoption or exploitation of a product, production process, service, management, or business method that is novel to the organization and which result in a reduction of environmental risk, pollution or other negative impacts of resources use (such as energy use) compared to relevant alternatives throughout its life cycle”. The 2007 review of the Environmental Technologies Action Plan (ETAP) defined eco-innovation as any innovation that benefits the environment, embracing technological innovation, process innovation and business innovation.

From 2008, the definitions of eco-innovation are approached from the industrial dynamics perspective. Andersen [2] defines eco-innovation as “innovations which are able to attract green rents of the market” and emphasizes that research on eco-innovations should focus on analyzing their integration into the economic process. Under this new approach the OECD [39] defines eco-innovation as “the creation or implementation of new, or significantly improved, products, processes, marketing methods, organizational structures and institutional arrangements which lead to environmental improvements compared to relevant alternatives”. In the same line of argumentation, Arundel and Kemp [3] stress that eco-innovations can be motivated by environmental or economic reasons, including objectives to reduce resources, waste management costs and the sale of eco-products.

The eco-innovation concept has been an interest of scholars from different disciplines such as economics [48], sociology [56] and management [45]; and its definition has been also widely discussed even in the dimensions of design, governance, users and supply chain [32,8]. Today, the term is used as synonym to “green innovation”, “sustainable innovation” and “environmental innovation” [53] and it covers many technologies (e.g. solar or wind energy systems), organizational practices (e.g. pollution prevention) and services (e.g. electrical roads).

In the interdisciplinary fields of environmental studies and innovation studies, there is a lack of comprehensive theories for eco-innovations. Understanding diffusion of eco-innovations has challenges to tackle. However, the topic attracts the attention of policy-makers and business actors because of its market potential and global concerns. Some eco-innovations are already at a mature stage that can compete with conventional alternatives. For example, photovoltaic (PV) market in Germany has already reached grid parity, a stage that PV can compete with conventional electricity sources [35]. Within increased mass production and improved technology efficiency, more and more eco-innovations become advantageous in different markets. According to these facts, this paper attempts to reveal the state-of-art review of the diffusion of eco-innovations literature and identify the main research streams of this interesting field.

3. Research methodology

The identification of the core contributors of a field is a common methodology to review an emerging literature. The point of departure for some studies is on the identification of top authors, top institutions, top journals, thematic focuses and clusters for innovations studies [16], the identification of most active scholars and journals for green innovation [53], and the identification of core research strands, key contributors and most-cited publications for sustainability transitions [37]. This paper focuses on the specific field of diffusion of eco-innovations and uses a descriptive methodology in three steps: firstly, the identification of the keywords and extraction the database using the Google Scholar database and the software Publish or Perish, a software program that retrieves and analyzes academic citations, and presents the statistics [25]; secondly, the quantitative analysis of the database, including the identification of the major contributors (journals and authors); finally, the identification of the main research streams and school of thoughts in a qualitative approach.

In this study, Google Scholar is used because of its more comprehensive citation coverage in comparison to ISI Web of Knowledge. Google Scholar is a freely accessible scholarly web search engine that includes full-text journal articles, technical reports, preprints, theses, books, and other scholarly documents [49]. Although this database has recently been criticized by many scholars because of its shortcomings on bibliometric purposes [1,29], it is used for bibliometric studies mainly because of its broader coverage.

Table 1
Keywords used for compiling the database from Google Scholar.

	Diffusion category	Adoption category
Eco-innovation notion	Diffusion of eco-innovation Diffusion of eco-innovations Eco-innovation diffusion Eco-innovations diffusion	Adoption of eco-innovation Adoption of eco-innovations Eco-innovation adoption Eco-innovations adoption
Ecological innovation notion	Diffusion of ecological innovation Diffusion of ecological innovations Ecological innovation diffusion Ecological innovations diffusion	Adoption of ecological innovation Adoption of ecological innovations Ecological innovation adoption Ecological innovations adoption
Green innovation notion	Diffusion of green innovation Diffusion of green innovations Green innovation diffusion Green innovations diffusion	Adoption of green innovation Adoption of green innovations Green innovation adoption Green innovations adoption
Sustainable innovation notion	Diffusion of sustainable innovation Diffusion of sustainable innovations Sustainable innovation diffusion Sustainable innovations diffusion	Adoption of sustainable innovation Adoption of sustainable innovations Sustainable innovation adoption Sustainable innovations adoption
Environmental innovation notion	Diffusion of environmental innovation Diffusion of environmental innovations Environmental innovation diffusion Environmental innovations diffusion	Adoption of environmental innovation Adoption of environmental innovations Environmental innovation adoption Environmental innovations adoption

Due to its comprehensive citation coverage, the citation numbers of Google Scholar are usually around four times higher than ISI Web of Knowledge. For example, the study of Jaffe and Palmer [30] has a total citation of 142 in ISI Web of Knowledge and 589 in Google Scholar; the study of Nill and Kemp [38] has a total citation of 36 in ISI Web of Knowledge and 113 in Google Scholar.

The identification of keywords was a challenging step. There are many synonyms that refer to the notion "diffusion of eco-innovations". To counter this, the synonyms of both "diffusion" and "eco-innovations" are separately identified to create multiple genitive constructions. Firstly, "adoption" is identified as the only synonym of diffusion due to the fact that these two terms are traditionally studied together [51,24,57]. The only difference is that adoption refers to a process at the individual level whereas the process of diffusion occurs in society. Secondly, "environmental innovations", "ecological innovations", "green innovations" and "sustainable innovations" are taken as synonyms to "eco-innovations" as suggested by Schiederig et al. [53].

According to these premises, the genitive constructions of the synonyms of the diffusion and eco-innovations were created as 40 variations as presented in Table 1. This approach limits the database and excludes the studies that do not include any of these 40 keywords. Therefore, the studies that about only one type of eco-innovations (e.g. solar panels, green textile or photovoltaic technology) would not appear in the database unless they have one of these 40 keywords in their text.

As a result of using the keywords listed in Table 1, a total of 1024 publications were extracted (including journals articles, conference papers, books, working papers and other scholarly documents) from Google Scholar database (extraction date 10 November 2012). The extracted publications were analyzed in a two-level analysis using information of the authors, journal names, publication years and citation frequency. The first level analysis provides an overview of the growth patterns, share of publications, top journals and more relevant authors according the number of citations. The second-level analysis focuses on the identification of the core disciplines and research streams by discussing the mostly cited articles. A total of 26 articles have been identified that have more than 10 citations per year.

4. Findings of the quantitative analysis

In the period 1990–2012, the number of publications that include the synonyms of "diffusion of eco-innovations" has reached a total of 1024 publications. Fig. 1 shows that very little research was conducted in the last decade of the last century to the diffusion of eco-innovations. However, since 2000 the term begins to become important. Starting from 2006 it grows strongly, as evidenced by 36% of these publications have been published in the period 2008–2011. Furthermore, yearly publications in the literature represent a growth of 64% from 2010 to 2011. However, and surprisingly, only 18% of these publications have cited Rogers (183 of 1024 publications). This trend was in a similar manner in the last years: 24%, 14% and 22% of yearly publications in 2009, 2010 and 2011 respectively have cited Rogers.

The database was divided into four groups according to number of citations per year. These groups includes the papers that have less than 1 citations per year, between 1 and 5 citations per year, between 6 and 10 citations per year and more than 10 citations per year. Fig. 2 reveals that most of the publications receive less than 1 citation per year (70%), while 22% receive between 1 and 5 and 5% between 6 and 10 citations per year. The publications that receive more than 10 citations per year only represent 3% of the dataset and represent 30 publications.

Regarding to the publications that receive more than 5 citations per year, three journals stand out with higher contribution: Ecological Economics, Journal of Cleaner Production and Technological Forecasting & Social Change (Fig. 3). These journals are well known for the scholars and their main features are related to the environmental aspects with the perspectives of economy, sociology or management. Energy Policy appears as the top journal for the authors that cite Rogers in the database while the articles

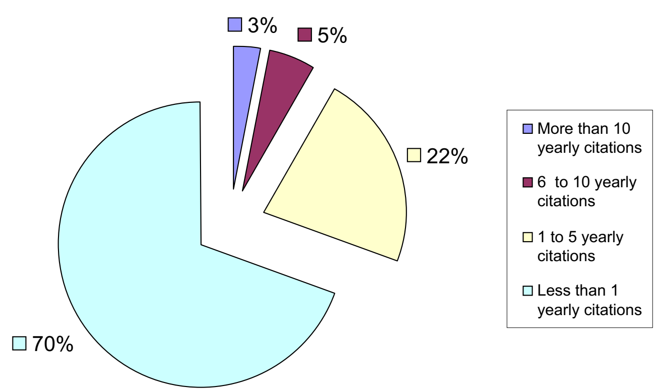


Fig. 2. Share of publications according to citation/year.

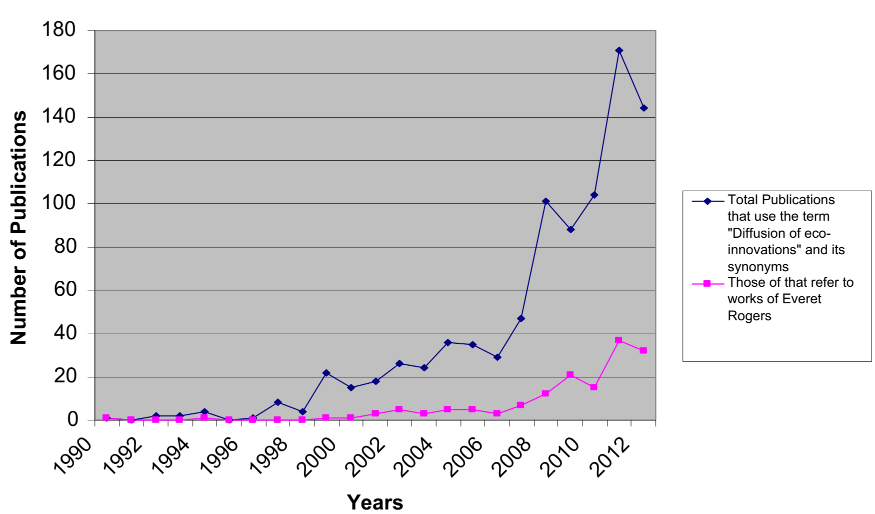


Fig. 1. Development of annual publications.

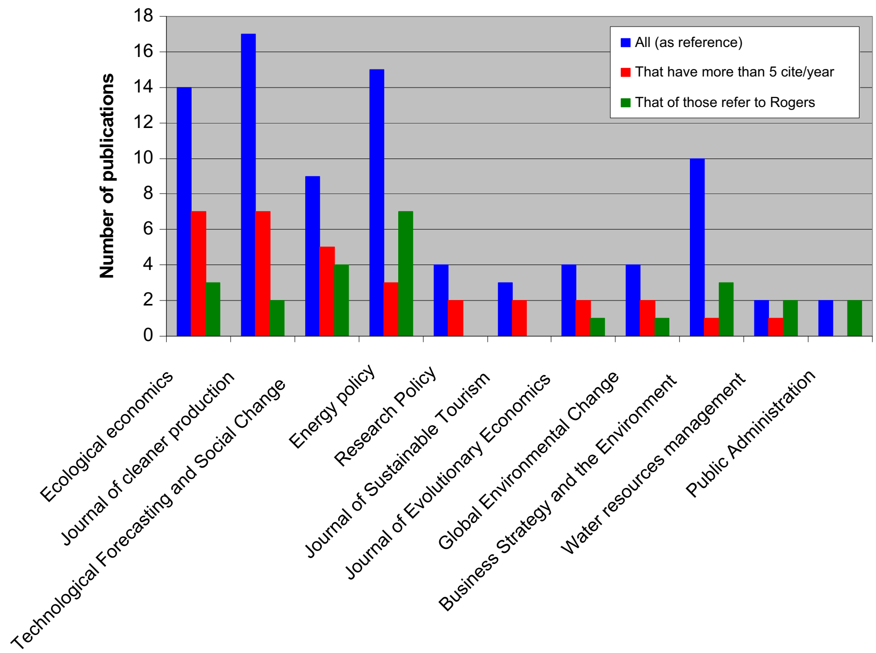


Fig. 3. The top journals for the publications with more than 5 citations/year.

appearing in Research Policy and Journal of Sustainable Tourism do not cite any work of Rogers.

Table 2 reveals the journal articles that receive more than 10 citations per year and the most active scholars in the diffusion of eco-innovations field. Technological Forecasting & Social Change and Ecological Economics are the top journals with 4 publications in the list of top contributors. Among the top three scholars (appear more than one time in the list) are two German researchers. Klaus Rennings, vice-head of the research area Environmental and Resource Economics, Environmental Management of the Center of European Economic Research (ZEW) in Manheim (Germany), and Nina Schwarz, scientist at the division of Computational Environmental System at the Helmholtz Center for Environmental Research (UFZ) in Leipzig (Germany). The third author is Joseph Sarkis, Professor of Operations and Environmental Management at the Graduate School of Management (GSOM) at the Clark University in Worcester (United States).

5. Discussion

The second-level of our analysis focuses on the identification of the core disciplines and research streams by discussing the mostly cited articles. The results show that "diffusion of eco-innovations" has become a common term in different scientific communities, despite the lack of a seminal work which focuses on the concept of diffusion of eco-innovations. While some of the mostly cited articles contribute to our understanding of diffusion of eco-innovations, some of them have specific research focus such as the impact of environmental regulations on firm's performance [30], performance measurement of environmental supply chain management [26] or impact of corporate social performance on firm financial performance [28]. All articles are relevant for the interdisciplinary fields of the research in environmental studies and innovation studies.

Based on the review of relevant most cited articles, it has been possible to identify some interdisciplinary research streams within three disciplines (Economics, Sociology and Management) and two traditional research fields (Marketing and Agent Based Modeling) related to diffusion of eco-innovations.

5.1. Economics

The role of innovation in economic and social change is one the main focuses of innovation studies, and it is especially analyzed by scholars with a background in economics [15]. However, from an economic perspective, theoretical and methodological approaches to understand eco-innovations are still limited [48,14] and discussions are based on neoclassical tradition (environmental economics and innovation economics), evolutionary tradition and ecological economics.

Some of the key approaches are evolutionary environmental economics [14], evolutionary policy [38], and sectoral systems [40]. The other three approaches that mostly encompass the diffusion of eco-innovations are ecological modernization [31], sustainability transitions [60] and lead markets hypothesis [6]. However, these three approaches have different perspectives of focus. The approach of ecological modernization focuses on innovation oriented environmental policy (regulations, incentives, policies, actors, etc.) and the supply-side driving forces of diffusion of eco-innovations with the underpinnings of sociological theory. The approach of sustainable transitions focus on long-term, multi-dimensional and fundamental transformation processes through which established socio-technical systems (sectors like energy supply, water supply, or transportation) shift to more sustainable modes of production and consumption [37]. Sustainability transitions are about interactions between not only technology, policy and economics but also culture and public opinion [20]; therefore sustainability transition can provide insights about the diffusion process of eco-innovations. Finally, the approach of lead market hypotheses focus on the countries that are first in adopting an internationally successful innovations and it can be applied for understand the link between strict regulation and creation of lead markets [6] by giving insights about the dynamics of international diffusion of eco-innovations.

5.2. Sociology

The theory of diffusion of innovations [51] is limitedly used in the identified top studies of diffusion of eco-innovations and only six of the publications that receive more than 10 citations per year refer his work. It is clear that more insights are needed

Table 2
The journal articles with more than 10 citations/year (C/Y).

	C/Y	Author	Title	Year, Journal
1	36,8	Jaffe and Palmer [30]	Environmental regulation and innovation: a panel data study	1997, Review of Economics and Statistics
2	33,5	Sarkis et al. [52]	An organizational theoretic review of green supply chain management literature	2011, International Journal of Production Economics
3	29,6	Hervani et al. [26]	Performance measurement for green supply chain management	2005, Benchmarking: An International Journal
4	28,3	Nill and Kemp [38]	Evolutionary approaches for sustainable innovation policies: From niche to paradigm?	2009, Research Policy
5	28,0	Jaenicke [31]	Ecological modernization: new perspectives	2008, Journal of Cleaner Production
6	23,3	Spaargaren [56]	Sustainable consumption: a theoretical and environmental policy perspective	2003, Society and Natural Resources
7	22,0	Hull and Rothenberg [28]	Firm performance: The interactions of corporate social performance with innovation and industry differentiation	2008, Strategic Management Journal
8	20,0	Vanclay [61]	Social principles for agricultural extension to assist in the promotion of natural resource management	2004, Australian Journal of Experimental Agriculture
9	20,0	Hockerts and Wustenhagen [27]	Greening Goliaths versus emerging Davids–Theorizing about the role of incumbents and new entrants in sustainable entrepreneurship	2010, Journal of Business Venturing
10	18,7	Ottman et al. [41]	Avoiding green marketing myopia: Ways to improve consumer appeal for environmentally preferable products	2006, Environment
11	18,5	Faber and Frenken [14]	Models in evolutionary economics and environmental policy: Towards an evolutionary environmental economics	2009, Technological forecasting and social change
12	18,4	Beise and Rennings [6]	Lead markets and regulation: a framework for analyzing the international diffusion of environmental innovations	2005, Ecological economics
13	18,0	Truffer and Coenen [60]	Environmental innovation and sustainability transitions in regional studies	2012, Regional Studies
14	17,3	Florida and Davison [17]	Gaining from green management	2001, California Management Review
15	14,0	Frondel et al. [18]	What triggers environmental management and innovation? Empirical evidence for Germany	2008, Ecological Economics
16	14,0	Perkins and Neumayer [44]	Does the 'California effect' operate across borders? Trading-and investing-up in automobile emission standards	2012, Journal of European Public Policy
17	14,0	Graham-Rowe et al. [22]	Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: A qualitative analysis of responses and evaluations	2012, Transportation Research Part A: Policy and Practice
18	13,3	Simpson and Power [55]	Use the supply relationship to develop lean and green suppliers	2005, Supply Chain Management
19	13,3	Del Rio Gonzalez [10]	The empirical analysis of the determinants for environmental technological change: A research agenda	2009, Ecological Economics
20	13,0	Oltra and Saint Jean [40]	Sectoral systems of environmental innovation: an application to the French automotive industry	2009, Technological Forecasting and Social Change
21	11,5	Schwarz and Ernst [54]	Agent-based modeling of the diffusion of environmental innovations–An empirical approach	2009, Technological Forecasting and Social Change
22	11,0	Cruz [9]	Dynamics of supply chain networks with corporate social responsibility through integrated environmental decision-making	2008, European Journal of Operational Research
23	11,0	Barthel et. al. [4]	An integrated modeling framework for simulating regional-scale actor responses to global change in the water domain	2008, Environmental Modeling & Software
24	10,8	Cantono and Silverberg [7]	A percolation model of eco-innovation diffusion: the relationship between diffusion, learning economies and subsidies	2009, Technological Forecasting and Social Change
25	10,5	Ozaki [42]	Adopting sustainable innovation: what makes consumers sign up to green electricity?	2011, Business Strategy and The Environment
26	10,2	Wagner [62]	Empirical influence of environmental management on innovation: evidence from Europe	2008, Ecological Economics

from sociology of diffusion to understand the diffusion of eco-innovations [10]. The theory of diffusion of innovations may help us on understanding the social norms of adopters and the social values of societies affecting the diffusion of eco-innovations.

Inside the discipline of sociology, on the one hand, the study of Spaargaren [56] introduces an interesting approach from environmental social sciences. This study brings the issues of sustainable consumption and lifestyles by using the social practices model of sociology. The proposed model indicates that diffusion of eco-innovations through citizen-consumers can be increased when daily routines (clothing, food, shelter, travel, sport, and leisure) are taken as a starting point for policymaking. On the other hand, the study of Ozaki [42] combines the theories of diffusion of innovations, cognitive and normative behavior, and consumption in order to understand the motivation factors of eco-innovation consumers by focusing on the five factors: perceived benefits, social influence, perceived compatibility, controllability and perceived uncertainty.

5.3. Management

The diffusion term in management of innovation is usually used for diffusion of environmental innovations within the organizations, especially for environment friendly practices. The adoption of Environmental Management Systems (EMS), a total quality approach on management of an organization's environmental programs, has taken much attention of scholars. On the one hand, Florida & Davison, [17] discuss on the factors that make firms to adopt EMS, and Frondel et al. [18] research on the role of EMS for the adoption of technical eco-innovations in firms. On the other hand, Wagner [62] focuses on the impact of EMS and

environmental managerial activities on the probability of firms to carry out eco-innovations.

The field of research in entrepreneurship, relevant for the management discipline, also contributes the understanding for eco-innovations. In this field, the study of Hockerts and Wüstenhagen [27] reveals the relation between firm size and diffusion of eco-innovations, theorizing the interplay between incumbents and new entrants.

5.4. Marketing

After the seminal work of Bass [5] that presented the first purchase growth of a new durable product in the market, the field of marketing has embraced a common research tradition for diffusion of innovations. However, the study of Ottman et al. [41] is the only one focusing on marketing in the list of top studies of diffusion of eco-innovations. These authors discuss on improved environmental quality and customer satisfaction in the concept of green marketing. They indicate the importance of three green marketing principles to make green products desirable for consumers: consumer value positioning, calibration of consumer knowledge, and credibility of product claims.

5.5. Agent based modeling

Agent based models refer to the models which consist of a set of agents that encapsulate the behaviors of the various individuals that make up the system by emulating these behaviors [43]. This research tradition, within the growing computational power, has been increasingly applied to social and economic problems previously modeled with nonlinear differential equations [47]. Evolutionary economics' principles can be formalized in the framework of agent based modeling as well [14].

There are three publications focused on agent based modeling in the list of top journal articles of diffusion of eco-innovations. The study of Schwarz and Ernst [54] is an empirical approach on agent-based modeling of the diffusion of environmental innovations, and their model implementation is based on differentiating individuals, communication, innovation characteristics and decision algorithms. The study of Barthel et al. [4] makes use of a multi-actor simulation framework by simulating decision-making process of the relevant actors, while Cantono and Silverberg [7] develop a model of innovation diffusion that combines contagion among consumers with heterogeneity.

6. Conclusions and future research

Research in the last decades has generated different predictive models to explain the diffusion of technological innovations (products and processes) and non-technological innovations (information, ideas) in different contexts. Today we know many of the attributes or factors that affecting the diffusion and adoption of innovations, such as the characteristics of the innovations, the adopters and the environment. However, there is very little knowledge on the relative importance of the different factors, and some disagreements over the direction of relationships, especially in the case of eco-innovations. Many different fields such as economics, marketing, sociology and anthropology provide interesting insights, but are not sufficient to understand in the context of eco-innovations.

In recent years, the importance of understanding diffusion of eco-innovations has been growing both in practice and academia. The European Union, international organizations and many countries are supporting the reduction of environmental risks and negative impacts of resource use through the implementation of innovation policies focused on the use of eco-innovations. However in the literature, although there are some concepts about management of eco-innovations, there is no comprehensive review on the knowledge base of diffusion of eco-innovations.

Responding to this challenge, in this paper we have identified the increasing interest of the scientific world in this emerging field. Using bibliographical evidence, our research has identified relevant journals and a small number of leading scholars that are recognized by different researchers in the field. To some extent, we have identified what can be called as the initial base of the cognitive platform that characterizes the diffusion of eco-innovations field. There are different disciplines leading to different streams of research. We have found that lead market hypothesis, sustainable transitions and the ecological modernization appear as some of the relevant leading research streams on the understanding of diffusion of eco-innovations, which might be the way forward to developing this field. We also identified that the linkage with the Rogers theory of diffusion is very limited in this emerging literature. The analysis of the linkage between eco-innovations concept and diffusion of innovations theory could be one of the promising areas for future research. We suggest enhancing understanding on consumers' behavior and decision process due to the fact that some eco-innovations have already reached a stage development to survive without policy support.

Acknowledgments

This research was conducted within the framework of the European Doctorate in Industrial Management (EDIM) which is funded by The Education, Audiovisual and Culture Executive Agency (EACEA) of European Commission under Erasmus Mundus Action 1 program. We thank to anonymous reviewers for their constructive suggestions. In addition, we also thank to the participants of IAMOT 2013 Conference for their valuable comments on the previous version of this paper.

References

[1] Aguillo IF. Is Google Scholar useful for bibliometrics? A webometric analysis Scientometrics 2011;91(2):343–51.

[2] Andersen MM. Eco-innovation. Towards a taxonomy and a theory. In: Proceedings of the 25th DRUID Conference 2008 on Entrepreneurship and Innovation – Organizations, Institutions, Systems and Regions. Copenhagen, Denmark; 2008.

[3] Arundel A, Kemp R. Measuring eco-innovation. Maastricht: United Nations University – Maastricht Economic and Social Research and Training Centre on Innovation and Technology; 2009.

[4] Barthel R, Janisch S, Schwarz N, Trifkovic A, Nickel D, Schulz C, et al. An integrated modeling framework for simulating regional-scale actor responses to global change in the water domain. Environ Model Softw 2008;23 (9):1095–121.

[5] Bass FM. A new product growth for model consumer durables. Manag Sci 1969;15(5):215–27.

[6] Beise M, Rennings K. Lead markets and regulation: a framework for analyzing the international diffusion of environmental innovations. Ecol Econ 2005;52 (1):5–17.

[7] Cantono S, Silverberg G. A percolation model of eco-innovation diffusion: the relationship between diffusion, learning economies and subsidies. Technol Forecast Social Change 2009;76(4):487–96.

[8] Carrillo-Hermosilla J, del Río P, Könnola T. Diversity of eco-innovations: reflections from selected case studies. J Cleaner Prod. 2010;18(10–11):1073–83.

[9] Cruz JM. Dynamics of supply chain networks with corporate social responsibility through integrated environmental decision-making. European Journal of Operational Research 2008;184(3):1005–31.

[10] del Río González P. The empirical analysis of the determinants for environmental technological change: a research agenda. Ecol Econ 2009;68 (3):861–78.

[11] European Commission 2011. Analytical report: attitudes of European entrepreneurs towards eco-innovation. Flash Eurobarometer Series #315. Hungary: European Commision.

[12] EIO. The eco-innovation challenge: pathways to a resource-efficient Europe. Eco-innovation observatory. In: M.M., M.O., S.G., Bleischwitz R, editors. DG Environment. Brussels: Eco-Innovation Observatory (EIO); 2011.
[13] ETAP. Clean, clever, competitive eco-innovation for a sustainable future, newsletter issue 18. Brussels, Belgium: European Commision; 2010.
[14] Faber A, Frenken K. Models in evolutionary economics and environmental policy: towards an evolutionary environmental economics. Technol Forecast Social Change 2009;76(4):462–70.
[15] Fagerberg J, Fosaas M, Sapprasert K. Innovation: exploring the knowledge base. Res Policy 2012;41(7):1132–53.
[16] Fagerberg J, Verspagen B. Innovation studies – the emerging structure of a new scientific field. Res Policy 2009;38(2):218–33.
[17] Florida R, Davison D. Gaining from green management: environmental Management Systems inside and outside the factory. Calif Manag Rev 2001;43(3):64–86.
[18] Frondel M, Horbach J, Rennings K. What triggers environmental management and innovation? Empirical evidence for Germany Ecol Econ 2008;66(1):153–60.
[19] Fussler C, James P. Driving eco-innovation: a breakthrough discipline for innovation and sustainability. London: Pitman Publishing; 1996.
[20] Geels FW. The multi-level perspective on sustainability transitions: responses to seven criticisms. Environ Innov Soc Trans 2011;1(1):24–40.
[21] Geroski PA. Models of technology diffusion. Res Policy 2000;29:603–25.
[22] Graham-Rowe E, Gardner B, Abraham C, Skippon S, Dittmar H, Hutchins R. Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: A qualitative analysis of responses and evaluations. Transportation Research Part A: Policy and Practice 2012;46(1):140–53.
[23] Griliches Z. Hybrid corn: an exploration in the economics of technological change. Econom J Econom Soc 1957;25(4):501–22.
[24] Halila F. The adoption and diffusion of environmental innovations [Doctoral thesis]. Lund University of Technology; 2007.
[25] Harzing A. Publish or perish. ISSI Newsletter 3(1); 2007.
[26] Hervani AA, Helms MM, Sarkis J. Performance measurement for green supply chain management. Benchmarking: Int J 2005;12(4):330–53.
[27] Hockerts K, Wüstenhagen R. Greening Goliaths versus emerging Davids – theorizing about the role of incumbents and new entrants in sustainable entrepreneurship. J Bus Ventur 2010;25(5):481–92.
[28] Hull C, Rothenberg S. Firm performance: the interactions of corporate social performance with innovation and industry differentiation. Strateg Manag J 2008;29:781–9.
[29] Jacsó P. Google Scholar duped and deduped – the aura of “robometrics”. Online Inf Rev 2011;35(1):154–60.
[30] Jaffe A, Palmer K. Environmental regulation and innovation: a panel data study. Rev Econ Stat 1997;79(4):610–9.
[31] Jänicke M. Ecological modernization: new perspectives. J Cleaner Prod 2008;16(5):557–65.
[32] Kemp R, Foxon T. Typology of eco-innovation. Project Paper: Measuring Eco-Innovation; 2007. p. 1–24.
[33] Kemp R, Pearson P. Final report of the MEI project measuring eco innovation. UM MERIT. 2007.
[34] Kemp R, Arundel A. Measuring eco-innovation. Technical Report, United Nations University, UNU-Merit. 2009.
[35] Lettner G, Auer H. Realistic roadmap to PV grid parity for all target countries. In: Proceedings of the 12th IAEE European Energy Conference. University of Venice: Italy; September 9–12, 2012.
[36] Mansfield E. Technical change and the rate of imitation. Econom: J Econom Soc 1961;29(4):741–66.
[37] Markard J, Raven R, Truffer B. Sustainability transitions: an emerging field of research and its prospects. Res Policy 2012;41(6):955–67.
[38] Nill J, Kemp R. Evolutionary approaches for sustainable innovation policies: from niche to paradigm? Res Policy 2009;38(4):668–80.
[39] OECD. Eco-innovation in Industry: enabling green growth. Paris: OECD; 2009.
[40] Oltra V, Saint Jean M. Sectoral systems of environmental innovation: an application to the French automotive industry. Technol Forecast Social Change 2009;76(4):567–83.
[41] Ottman J, Stafford E, Hartman C. Avoiding green marketing myopia: ways to improve consumer appeal for environmentally preferable products. Environment 2006;48(5):24–36.
[42] Ozaki R. Adopting sustainable innovation: what makes consumers sign up to green electricity? Bus Strat Environ 2011;20(1):1–17.
[43] Parunak HVD, Savit R. Agent-based modeling vs. equation-based modeling: a case study and users' guide. In: Proceedings of multi-agent systems and agent-based simulation (MABS'98). Springer, LNAI 1534; 1998. p. 10–25.
[44] Perkins R, Nuemayer E. Does the ‘California effect’ operate across borders? Trading-and investing-up in automobile emission standards Journal of European Public Policy 2012;19(2):217–37.
[45] Pujari D. Eco-innovation and new product development: understanding the influences on market performance. Technovation 2006;26(1):76–85.
[46] Rao KU, Kishore VVN. A review of technology diffusion models with special reference to renewable energy technologies. Renew Sustain Energy Rev 2010;14:1070–8.
[47] Rahmandad H, Sterman J. Heterogeneity and network structure in the dynamics of diffusion: comparing agent-based and differential equation models. Manag Sci 2008;54(5):998–1014.
[48] Rennings K. Redefining innovation – eco-innovation research and the contribution from ecological economics. Ecol Econ 2000;32:319–32.
[49] Vine Rita. Google scholar. J Med Libr Assoc 2006;94(1):97–9.
[50] Rogers EM. Diffusion of innovations. 1st Ed.. New York: The Free Press; 1962.
[51] Rogers EM. Diffusion of innovations. 5th Ed.. New York: The Free Press; 2003.
[52] Sarkis J, Zhu Q, Lai K. An organizational theoretic review of green supply chain management literature. Int J Prod Econ 2011;130(1):1–15.
[53] Schiederig T, Tietze F, Herstatt C. Green innovation in technology and innovation management – an exploratory literature review. R & D Manag 2012;42(2):180–92.
[54] Schwarz N, Ernst A. Agent-based modeling of the diffusion of environmental innovations – an empirical approach. Technol Forecast Social Change 2009;76 (4):497–511.
[55] Simpson DF, Power DJ. Use the supply relationship to develop lean and green suppliers. Supply Chain Management 2005;10(1):60–8.
[56] Spaargaren G. Sustainable consumption: a theoretical and environmental policy perspective. Soc Nat Resour 2003;16(8):687–701.
[57] Suriñach J, Autant-Bernard C, Manca F. The diffusion/adoption of innovation in the internal market. Eur Econ – Econ Pap 384 2009;1(11):1829–41.
[58] Tarde G. The Laws of Imitation. New York: Henry Holt and Company; 1903.
[59] Tidd J. Gaining Momentum. Managing the diffusion of innovations. New Jersey: World Scientific; 2010.
[60] Truffer B, Coenen L. Environmental innovation and sustainability transitions in regional studies. Reg Stud 2012;46(1):1–21.
[61] Vanclay F. Social principles for agricultural extension to assist in the promotion of natural resource management. Australian Journal of Experimental Agriculture 2004;44(3):213–22.
[62] Wagner M. Empirical influence of environmental management on innovation: evidence from Europe. Ecol Econom 2008;66(2–3):392–402.
[63] Wissler C. The influence of the horse in the development of plains culture. Am Anthropol 1914;16(1):1–25.
[64] Wissler C. The diffusion of horse culture among the North American Indians. Anthropogical Papers of the American Museum of Natural History; 1915. p. 254–256.